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THESIS

THE CASUALTY NETWORK SYSTEM CAPSTONE PROJECT

by

Ethan A. Miles

December 2012

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This capstone project first describes the current problem of battlefield patient handoffs. The project next explores the tactical network as a solution, suggesting specific attributes of an ideal system. Finally, this project explores applications for a Casualty Network System and discusses how such a system should be implemented.

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THE CASUALTY NETWORK SYSTEM CAPSTONE PROJECT

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PREFACE

This capstone project was born out of my direct experiences while deployed to Iraq and Afghanistan as a Ranger Battalion Surgeon. While deployed I noticed that each receiving provider in the evacuation process had essentially zero knowledge of the patient at the time they started to care for them. TACEVAC medics were arriving with little knowledge of patient injuries, how many patients they were receiving and sometimes whether they were human or canine. I observed that rarely did a casualty card make it to the Combat Support Hospital (CSH) trauma team. When the casualty card did make it to the CSH, often it was thrown on the floor with the rest of the casualties clothing. The casualties would invariably get repeat doses of medications, or have delays in discovering wounds. Why was this critical patient summary being so blatantly discarded? Why was the work of my highly trained medics being overlooked? I came to realize that it was not the fault of the trauma team.

The problem with the system was that the trauma team was starting with a blank canvas in their mind. Rightly so, the trauma team would go straight to the patient for their information. The directly observed information was used to paint their picture of the casualty. While our military trauma teams are exceptionally proficient at their jobs, I often thought about what we could do in the field to help them paint a more accurate picture. One answer stood out clearly, the trauma team must have the information before they receive a patient so that they can start to “see the patient” before he or she arrives.

I argue that since handoffs in the civilian environment have been shown to be a problem, we can assume that they are just as much of a problem in the battlefield. While there are currently no studies to back up this assumption, I believe that it is a safe assumption to make. Further, I argue that the way to fix this problem in the battlefield (or at home) is to send the information to the receiving provider before the casualty arrives.

Solutions, though currently less than ideal, exist for this problem. Why then, are we still having medics on the battlefield use markers and laminated pieces of paper? The answer, I believe, is that while the technological means may exist, the guidance does not. This project attempts to help solve the guidance problem by explaining the problem, recommending a solution and laying out the way ahead.

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LIST OF ACRONYMS AND ABBREVIATIONS

AED – Automatic External Defibrillator

AF – Assault Force

ARS – Acute Radiation Sickness

CBRN – Chemical, Biological, Radiological and Nuclear

CNS – Casualty Network System

CONUS – Continental United States

COTS – Commercial Off The Shelf

CP – Counter-Proliferation

CSH – Combat Support Hospital

DoD – Department of Defense

ECG – Electrocardiogram

EM – Evacuation Module

EMS – Emergency Medical Services

FST – Forward Surgical Team

HADR – Humanitarian Assistance/Disaster Relief

IBD – Individual Biometric Device

JTAC – Joint Terminal Attack Controller

LPD – Low Probability Detection

LPI – Low Probability Intercept

MD – Medical Doctor

MEDEVAC – Medical Evacuation

MM – Medic Module

MTF – Military Treatment Facility

OC – Observer Controller

RF – Radio Requency

RR - Respiratory Rate

RTO – Radio Telephone Operator

SEB – Staphylococcal Enterotoxin B

SER – Software Enabled Radio

SME – Subject Matter Expert

SOCOM – Special Operations Command

SOF – Special Operations Forces

START – Simple Triage Rapid Treatment

TACEVAC – Tactical Evacualtion

TM – Trauma Module

TNT – Tactical Network Testbed

TOC – Tactical operations Center

UHF – Ultra High Frequency

EXECUTIVE SUMMARY

When a casualty is received during combat operations, a lifesaving clock starts ticking. The faster he can get to definitive medical care, the better the chance he has of surviving. Currently minimal to no information about the casualty is received ahead of time by the provider. Despite having an intimate knowledge of the casualties and their injuries, the field medic has only minimal ability to pass this knowledge on to the next provider.

Ideally, before receiving casualties, a provider will have an understanding about their injuries and conditions. In order to accomplish this, information must be sent ahead of time. Currently, technology exists to enable this to happen anywhere in the world in a variety of circumstances. An ideal system will allow critical information to flow from casualties and attending medic to all receiving providers in the evacuation chain, starting as close to the time of injury as possible.

The tactical network formed by the military unit on the ground provides a means in which casualty information can be transmitted. By linking casualties and providers via the tactical network, medical information can be passed back and forth instantly. This networked connection connects all providers to the casualties, facilitating improved handoffs and casualty care.

The design requirements of a Casualty Network System (CNS) consist of two categories: medical and communication. Medical requirements include types of vital signs required, casualty information, and injury information. Communication requirements include: method of signal propagation, wireless signals, and user interface. The initial design requirements must be set, yet remain flexible as new technologies breakout and units change their requirements.

Applications for a CNS are numerous. Four main areas discussed for use include: combat casualty care, CBRN operations, Humanitarian and Disaster

Response (HADR), and civilian EMS. As long as interoperability remains a clearly defined requirement, the applications are limitless throughout the medical field.

While the problem of casualty handoffs is a large one, a solution is in sight. The current level of ad-hoc mobile networking sets the framework for the real-world solution. In order to fix the problem, the DoD must lay out specific design requirements to the commercial industry for development and an experiment campaign must be organized. The most likely organization within the DoD to spearhead the process is SOCOM. SOCOM should take the lead for several reasons: they cross all services, have Research and Design capabilities, are staffed with highly qualified and experienced medical and communications personnel, are consistently accepting and adapting new technologies, and have the ability to rapidly field technologies.

ACKNOWLEDGMENTS

First and foremost, I would like to thank the medics who have served and are currently serving on the battlefield. This project will, I hope, help them do their jobs with greater efficiency and save more lives. I would also like to thank my advisor, Dr Alex Bordetsky, for guiding me on this project as well as for his commitment to advancing battlefield medical capabilities. A special thank you is in order to the Defense Analysis Department at the Naval Postgraduate School for encouraging and fostering free thinking as the student corps takes on the multitude of important issues facing our nation. Finally, I thank Valorie for standing by me throughout this process and the military journey we are on.

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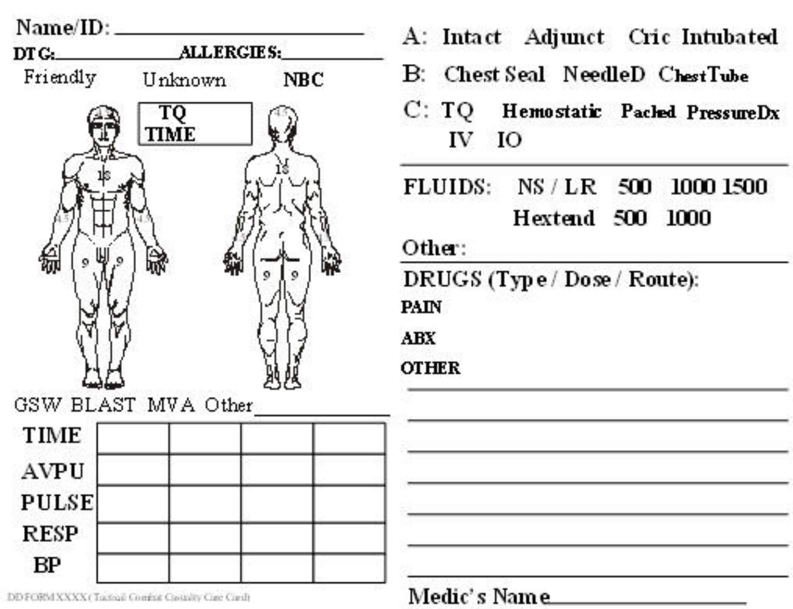
I. THE HANDOFF PROBLEM

The current concept of the tactical network is rapidly evolving on today’s battlefield. As Special Operations Forces (SOF) are rapidly acquiring software enabled radios and operating within a new bubble of information flow, the potentials are unlimited. One area with a tremendous opportunity exists in the medical care arena.

In today’s theatre of operation there is minimal communication at handoffs when a casualty is evacuated through the current medical evacuation (medevac) chain, significant gaps occur in the patient’s continuity of care. As the patient is transferred from the ground medic to the flight medic, and flight medic to trauma team minimal (if any) information is transferred along with the patient. Attempts in the past to overcome this gap in the battlefield handoff have been focused on the handwritten casualty card (Figure 1). Recent revision of this card resulted in a more intuitive and easier to use format, which captures essential data.


Name/ID: ____________________
DTG: __________ ALLERGIES: __________
Friendly Unknown NBC
TQ TIME
GSW BLAST MVA Other __________

TIME				
AVPU				
PULSE				
RESP				
BP				

DD FORM XXXX (Tactical Combat Casualty Care Card)

A: Intact Adjunct Cric Intubated
B: Chest Seal NeedleD ChestTube
C: TQ Hemostatic Packed PressureDx
IV IO
FLUIDS: NS / LR 500 1000 1500
Hextend 500 1000
Other:
DRUGS (Type / Dose / Route):
PAIN
ABX
OTHER
Medic’s Name __________

Figure 1. The current combat casualty card in use.

Other attempts to overcome this problem have been through the use of radio transmission or through sending the medic along with the patient. Radio transmission of patient information is often difficult at best as communication links are difficult between field units and trauma teams. Often the information is incomplete, short and incompletely transmitted. Sending the initial treating ground medic along with the casualty provides a source of tremendous information. The two main problems with this technique are: the ground unit loses a vital member for follow on operations, and the information is still being provided at time of casualty reception and not prior.

No matter how much the handwritten card is improved, however, the system of handwritten casualty cards is critically flawed. This primary flaw in this system is that it does not allow the receiving provider to obtain knowledge about the patient prior to receiving the casualty. When a provider receives a handwritten note at the same instant that the patient is received, they will (justifiably) focus on the patient rather than gain information obtained from the previous provider. The simultaneous reception of patient and information often results in casualty cards being ignored or discarded. In order to rectify this fundamental flaw a system must be developed which allows ahead of time transmission to the receiving provider.

Patient handoff has been shown to be a major source of medical errors in hospitals throughout the country. It is estimated that somewhere between 44,000 to 98,000 patients die in hospitals per year as a result of preventable medical errors (Council, 2000). In fact, when a study was performed looking for error at handoff in a post-op pediatric intensive care unit, miscommunication occurred in 100% of the 134 cases (Mistry KP, 2005). Much attention has been given on how to handle this problem and virtually all the solutions have focused on adequate communication about the patient prior to reception. Even when this communication does occur via spoken word, the amount of information processed by the receiver can be much lower. In a study performed at a level 1 civilian trauma center, the receiving provider documented only 72.9% of key data points transmitted by EMS personnel (Carter, Davis, & Evans, 2009). This study emphasizes that even when key data is verbally transmitted in a controlled environment at the time the patient is received; much of that data is lost in the handoff. This furthers the argument that in order to properly receive information about a patient, it must be available ahead of time and in a digitally recorded format. By doing so, the error rate of transcription can be virtually eliminated. Another benefit of ahead of time transmission is that the receiving team has a great deal more time available to “learn” about their incoming patient and properly prepare for optimal care. While no studies have been done to assess the error rate in combat handoffs, it can be reasonable assumed that they are higher than would be seen in a much more controlled civilian environment. In combat with our most critical patients, this information is often partially transmitted over

In 2006, The Joint Commission decided to implement patient hand off in its requirements. The Commission stated, “The primary objective of a “hand off” is to provide accurate information about a [patient’s] care, treatment, and services, current condition and any recent or anticipated changes. The information communicated during a hand off must be accurate in order to meet [patient] safety goals (Joint Commission, 2006).” It is an assumption in civilian medicine that this information flow will occur prior to receiving the casualty. Currently in today’s theatre of operations, little information is available about a patient prior to receiving them at the MEDEVAC and FST/CSH. This lack of medical information presents several challenges for the MEDEVAC medic and receiving trauma team. These challenges include: How many patients, what are their exact injuries, what treatments have been performed, what medications have been given, what is their blood type, how are their vitals trending, and what concerns does the medic who is currently treating them have. All of the information is available, yet it is not transmitted to those who need it most in time for them to adequately prepare to receive the patient.

Receiving information about a patient prior to receiving them presents several advantages. First, the receiving provider has time to adequately process and internalize the casualties' injuries, status and interventions received. Second, the receiving provider has time to properly prepare for the casualty, prepping specialty equipment such as femoral traction splints, blood transfusions or medications. Third, ahead of time transmission would facilitate transporting the patient to the most appropriate facility (such as reroute to a neurosurgical capable facility for the TBI patient). Fourth, ahead of time transmission would facilitate improved diagnostic capability. Imagine being able to trend a casualties vital signs for the hour prior to arrival at the hospital rather than basing treatment off of the information received in the 1 minute since they arrived in the hospital.

In the following chapter, I will describe the current tactical network as it relates to the networking of information flow in combat casualty care. This description will lie out the fundamental concepts of network theory and relate those concepts to the deficiencies in the current system.

II. THE TACTICAL MEDICAL NETWORK

The central core of the tactical network is the Assault Force (AF), which can be described as a cluster of nodes. Each node is an individual soldier with a software-enabled radio. Typically the AF is made up of approximately 40–70 members. Within the AF, only a limited number of personnel have software enable radios (SER's). Typically, the squad leaders and above carry SERs along with a few other enablers (JTAC, RTO, etc.). In the described scenario, there are approximately 9–12 nodes making up the ground tactical network. Given the high degree of connectivity between the AF, the separation between the nodes is extremely small as described by the Watts and Strogatz model (Watts & Strogatz, 1998). Based on the Watts and Strogatz model, the AF can be viewed as a small world network with several shortcuts. This arrangement facilitates a high degree of connectivity in the AF, which facilitates information flow from one member to another. The additional advantage of this network is that once a connection is formed to another network or hub, every member connected to the AF can now access the second network. At most, an individual in the AF is two degrees separated from the network (one degree to his team leader, two degrees to his squad leader who is directly in the network). This network may link in to various assets such as: UAV's, fixed-wing aircraft, rotary wing aircraft, or satellites which can link the entire network into a worldwide network (Internet gateway node) (Chlamtac, Conti, & Liu, 2003). These links provide a tremendous opportunity for TCCC that is the ability to tie all medical providers to each other. Thus, the AF network becomes the vital circuit to which the casualty must be connected.

Once a casualty is received a few key actions occur in this network. The first change is that the casualty is automatically placed one degree further than the medic from the network. This occurs because even if the casualty is the most connected node in the network, his radio is removed from him and all information flow goes through the medic attending to him. The medic now becomes a weak tie, connecting the casualty information to the AF network. A weak tie forms “a bridge to the outside world” allowing casualty information to flow into the network (Barabasi, 2002). Weak ties in networks form critical roles as they connect hubs to hubs, thus allowing one hub to access the information contained in another hub. In this example, the casualty represents the vital source of information while the medic links that information to the network. The second action that occurs is the introduction of the TACEVAC to remove the casualty and transport him to definitive care. Upon entering into radio frequency range of the AF, the pilot (for Air TACEVAC) links in to the network and becomes a weak tie. The pilot as a weak tie is connecting the AF to the back of the aircraft (the medic). Now, a connection is established from the casualty to the TACEVAC medic. This tenuous connection plays a critical role in the care of the casualty. The TACEVAC medic is charged with receiving a casualty (or multiple casualties) with little to no information about them, continuing optimal care in suboptimal conditions. The TACEVAC medic’s goal is to deliver the casualty to the next level of care in the same or better condition than he received them. When we compare this to the problems described earlier in patient handoffs in the hospital environment, it is easy to see what a tremendously difficult task this can be. Through the use of properly established networking protocols, a reliable end-to-end delivery can be made from the sender (ground medic) to the receiver (TACEVAC medic) (Chlamtac, Conti, & Liu, 2003). By establishing a connection to the casualty ahead of time, the TACEVAC medic gains improved situational awareness on his casualty, thus enhancing his ability to provide en route care. As we will see though, this connection has several difficulties.

Similar to the TACEVAC, one can see how connecting the network to satellite communications establishes a weak tie to the trauma team. The Trauma Team can range from a small Forward Surgical Team to a massive Combat Support Hospital or a CONUS based rear-echelon facility (i.e., Walter Reed). As shown in Figure 1, the casualty is two degrees from the tactical network and four degrees from either the TACEVAC or the trauma team. Similar to the TACEVAC medic, the Trauma Team is charged with receiving a casualty, of whom they know little to nothing about, and providing life saving definitive care. If the Trauma Team establishes a connection to the casualty ahead of time, they too will increase their situational awareness of the casualty. This increased situational awareness comes through an enhanced casualty handoff process, which must occur prior to reception of the patient.

The current difficulties with the tactical network are that the key medical players are not tied in. A ground medic may or may not (more likely the latter) have a software-enabled radio, the medic on the TACEVAC is likely to only have voice connection to the pilot, and the Trauma Team has no current connection to the network other than a voice relay of a 9 line MEDEVAC report. How then, do we connect these key nodes to the network? Each of the three nodes discussed have different requirements for optimal connection to the network.

When connecting to the AF network, the AF medic must have a secure wireless link. Connectivity can be accomplished by simply giving the medic a SER, thus becoming another node in the network. If however, limitations in resources prevent all medics from carrying a radio other means may suffice. One optimal way to connect the medic to the network is wirelessly, through a handheld device. Several devices exist that can wirelessly transmit to any node within the AF network. Currently, wireless handheld devices designed for medics exist and provide significant advantages. These devices can receive wireless transmission of multiple casualty vital signs, interpret voice into an electronic casualty card, and transmit two-way texting. By connecting the medic into the AF network in this way, a critical amount of casualty information becomes available to anybody tied into the network.

The TACEVAC medic has an increasing opportunity to tie into the AF network as helicopters increase their communications capabilities through software enable communications. If the TACEVAC medic ties into the AF network, then he will be able to receive this key information prior to receiving the casualty, as well as be able to push information back into the network once the casualty is received. The TACEVAC medic does not require the wireless connection like the AF medic does, it must still be a secure connection though. The connection of the TACEVAC medic may be direct plug in to the helicopter (or ground vehicle). The TACEVAC medic may also use a larger format tablet, instead of a small handheld device like the AF medic, thus increasing his ability to track multiple patients in a dark unstable environment.

Once a satellite connection is established with the AF network, outside sources may connect. These sources include the FST, CSH, and rear-echelon Military Treatment Facilities (MTF). By establishing this link, the awaiting Trauma Team now becomes a critical node in the medical network. The Trauma Team is now able to receive information (vital signs, casualty card information, location, messages, and personal information) as well as send information to the medics providing care. Most Trauma Teams are connected to the Internet via hospital based computer networks. These network provide the opportunity for a simple connection into a tactical network once satellite communication is established. Now the trauma team is better able to receive the patient as they have key handoff information ahead of time. The team is now able to activate the proper members (neurosurgery, orthopaedics, blood bank, etc.) armed with the casualty information. Additionally, when medics are faced with difficult medical decisions, they will now have the ability to reach back for telemedicine support.

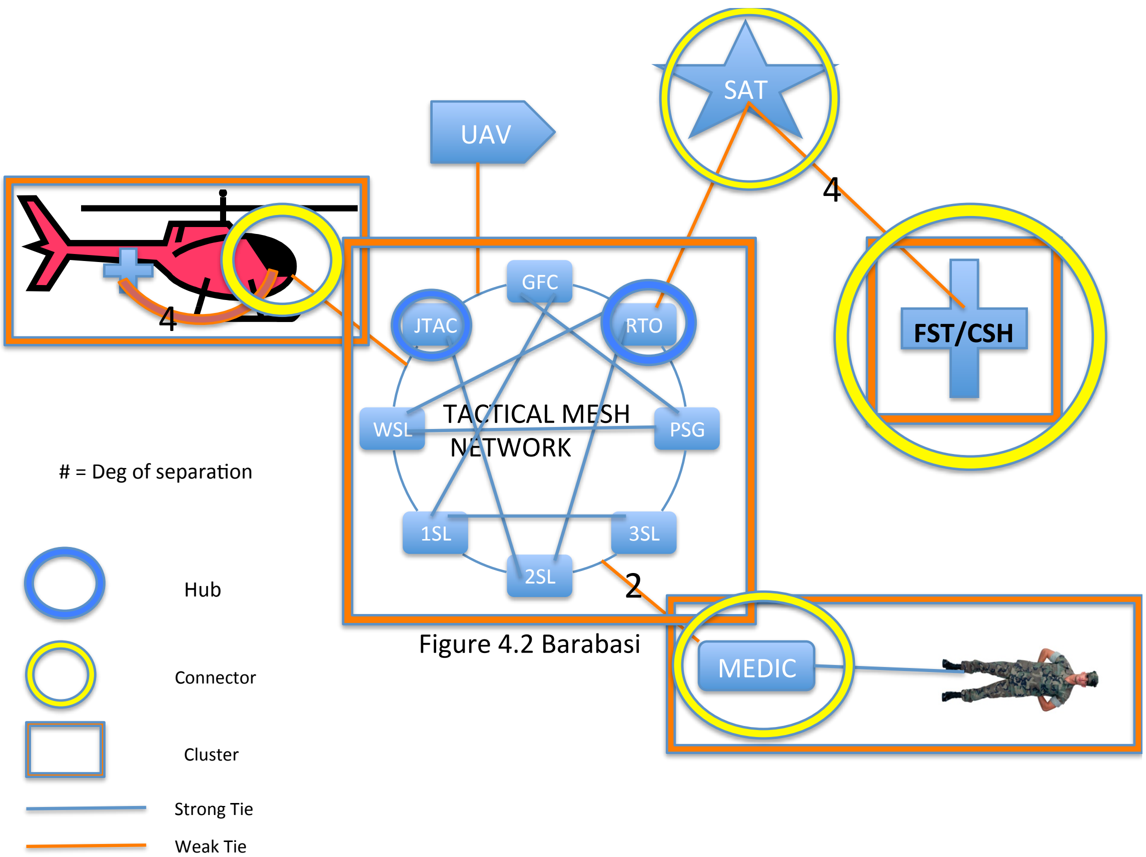


Figure 2. Graphic representation of the battlefield casualty network.

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III. SYSTEM DESIGN

The CNS consists of four distinct components. The first component is the individual biometric device (IBD). This is a small and rugged device, which is attached to the casualty. The device is capable of recording and transmitting a variety of vital signs such as: pulse rate, respiratory rate, SpO2, and skin temperature. The IBD transmits this data to the second component, the Medic Module (MM). Data transmission is done via secure wireless method, most likely utilizing Ultra-Wide Band for its tactical advantages of low probability intercept (LPI), low probability detection (LPD), high resistance to jamming, low interference and high data rate (Battaglia, 2011).

The MM is a small (cell-phone-sized) rugged device, which can attach to the medic in any desired configuration (chest, arm, pocket, or to patient directly). The MM device captures all data transmitted from the IBD recording and displaying graphically, thus allowing the medic to trend vital signs. The device is able to record multiple patients and allows for easy switching between patients. The device has a minimum of four separate screens. Screen 1 is essentially a vital signs monitor (with trends), screen 2 is the injury and treatment screen (similar to the current casualty card), screen 3 is individual patient data (allergies, blood type, identification, and screen 4 is a messenger screen for 2 way communication (from medic to medevac or trauma team). The patient's identification appears at the top of all screens (verification). The MM records information on the casualty's injuries and the medic's treatments via voice recognition. As the medic performs his primary survey he speaks into the system any injuries and interventions performed. These injuries and interventions are recorded and displayed on screen 2. Once the primary survey is complete and the patient is stabilized, the medic can quickly review screen 2 and confirm that the data recorded is correct. The information is either manually corrected on the device by the medic or confirmed as correct. Once the decision has been confirmed to medevac the patient, the medic activates the transmission mode on the device, sending all data to the third and fourth components, the Evacuation Module (EM) and Trauma Module (TM). The information is sent via tactical communications networks, either FM or adhoc tactical networks.

The EM is essentially a larger version (tablet size) of the MM, which allows for easier visualization and data entry aboard helicopter or ground ambulance. Once the patient data is transmitted from the ground medic, the evac medic can see all four screens and send messages to the ground medic (confirming arrival time, patient load plan, etc.). Once the patient is received by the medevac, the IBD transmits information directly to the EM, which then takes over transmitting duties to the TM. The medevac medic confirms the data; updates screen 2 and continues to transmit medical data to the awaiting trauma team. Transmission is achieved securely through direct plug in capability from existing aircraft systems.

The TM is not a separate device; rather it is a software program, which uses data transfer to a secure Internet site. If a remotely staged FST does not have Internet capability, they can use an EM. This vital capability opens up the possible use of the system to engage remote Subject Matter Experts (SMEs). The system overall must meet several requirements.

Establishing the design requirements is the most important task of the project. Design requirements will be based off of initial concept and refined through interviews and testing feedback. Initial design requirements have been set and are as follows:

Interoperability. The system must be able to work with multiple devices from different manufactures. Rather than focus on a single system design, each service or unit must be able to purchase components that best suit their operators. Often on today’s battlefield several services and countries may come together during the casualty care process. A marine may be injured, transferred via Army TACEVAC to an Air Force or British hospital. In order to ensure that these systems work together, interoperability standards must be set by the DoD.

The experimentation campaign described earlier will help facilitate interoperability between the different components.

"Ahead of time transmission." The system must be able to transfer casualty data to the receiving provider, prior to casualty arrival. If casualty data is transmitted ahead of time to the receiving party, then they will have time to prepare (both mentally and logistically) to receive the casualty. If data is received at the same time as the casualty is received, then naturally the priority will go towards evaluating the casualty rather than learning from what the prior provider has done. This data should be able to be transferred to the receiving trauma team as well as the medevac crew.

Secure transmission. The system must work under secure encrypted transmission. As with all battlefield communication, it is critical that this data be securely transmitted.

Redundancy. Given the critical nature of this system, each step must have redundancy and backup for when systems fail.

Confirmation. Each transmission must be confirmed upon receipt. By confirming transmission, the provider is ensured that the receiving party has the required information.

Intuitive interface. This system will be used during the highest stress times on the battlefield, so interface must be simple and intuitive. A complicated device will quickly get thrown to the side when first contact is made.

Multiple casualties. The system must be able to work with multiple casualties (as is often seen on the battlefield) with ensured positive identification. The provider must be able to assess and treat multiple casualties simultaneously. A minimum of five casualties should be the goal for each MM.

Multiple providers. The system must be capable of handling more than one provider. Often on the ground more than one medic is available, the two must be able to integrate on the system to facilitate patient coordination and care.

Positive identification. The system must be able to quickly and positively identify the casualty. Ideally this confirmation would also include allergy, blood type and any additional critical medical history for the casualty.

Low light capability. Given that the system will be used in a time of combat and often at night, the system must have the ability to operate putting out minimal light signature for operational security.

Air worthy. The system must be able to operate in rotary wing airframes.

Rugged. Each module must be capable of operating in the extremes of environmental conditions seen throughout the world.

Ease of data entry. Data entry into the system must be extremely simple and take minimal time and effort away from casualty care. Data recording should never interfere with patient care. Optimally this would be a hands free voice system. A hands free voice system is particularly well suited to the ground medic as medics in the military are required to vocalize their primary and secondary surveys during training.

Compatible with protective gear. The system must be compatible with current protective gear worn, to include gloves.

Biometric recording. Ideally the system would use remote real-time biometric data recording. This capability would greatly increase the utility for the ground medic, thereby increasing the odds that the system will be used.

Scalability of data flow. When casualties are received on the battlefield, it is very likely that there will be numerous demands for bandwidth through the tactical network. Priority of bandwidth will always go to the operators engaged fighting the enemy (and preventing further casualties). During these times the

CNS system must be able to automatically decrease the throughput, sending the most vital information at a reduced data rate. For example, the CNS may send only a pulse rate every 60 seconds when the network is stressed. When more bandwidth becomes available, the CNS "catches up" by sending backlogged data and decreasing the intervals between vital signs.

Add-ons. The system should be capable of being built upon to create the system additions that will likely be requested when tested. Such additions may include: GPS with casualty locating capability, casualty alert that the wounded soldier could use to alert a medic when wounded, simple trauma protocols, interface with current CBRN detectors, blood typing and lab capabilities.

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IV. APPLICATIONS

A. CBRN

The capabilities of such a network system extend far beyond basic combat casualty care enhancement and into the CBRN and counter-proliferation realm. Given the remote biometric and two-way communication ability of the system, it is particularly well suited for high risk or contaminated areas. The IBD may be used on all team members involved in a particular mission, while the video enabled MM is carried by one of the team members. Alternately, the MM could be attached to an unmanned vehicle inserted with the team. This unmanned vehicle could remotely monitor, visualize and interact with the casualties on the ground. The command element can remotely monitor biometric data of each individual on the team. When the MM is combined with CBRN sensor detection, the device will alert in the network to exposures. By remotely monitoring the team's vital signs, the command element can watch for early signs of exposure, particularly to chemical agents. With two way and video communication, the team can take instruction from SME's anywhere in the world regarding their medical care. By equipping the team members with technology to monitor and respond, the medical response is thereby greatly hastened.

1. Select Properties of Chemical Agents

In general, chemical agents can be categorized as one of four types of agents: Nerve, Blister, Blood or Pulmonary. Nerve agents act primarily on the Acetylcholinesterase pathway and can cause death in 15 minutes to 42 hours (USAMRIID (United States Army Medical Research Institute for Infectious Disease, 2011). Blister or Vesicant agents work by causing damage to the skin, lungs and eyes. The onset of physiological effects from Blister agents is generally very quick as well. Blood agents like the cyanide based chemicals work to bind hemoglobin, preventing the exchange of CO_2 and O_2 in the lungs, thus showing physiologic changes rather quickly. The final class, pulmonary agents, work by rapidly damaging the respiratory tract thereby decreasing the ability to exchange CO2 for O2. Since the chemical agents have rapid physiological effects, the utility of monitoring vital signs is obvious. By constantly monitoring vital signs of the team involved early clues of exposure (such as decreased SpO2, increased respiratory rate and increased pulse) can be identified.

2. Select Properties of Biological Agents

Biological agents include viral, bacterial and fungal agents. In general they can either cause disease by infecting the individual (like anthrax), or by toxic effects of the agent's metabolites (like SEB). Toxic effects of the metabolites generally act like chemical agents and produce effects similar to those described above. The infectious agents have variable incubation periods, in general at least 24 hours. The infectious biological agents can be very difficult to diagnose when first encountered, even by experienced physicians as many of their symptoms overlap common human infections. For example, inhalational anthrax generally presents with fever, headache and cough.

3. Select Properties of Nuclear Agents

Radiological exposure results in a wide spectrum of radiologic illness, which is primarily dose dependent. The effects seen from radiologic exposure range from burns to GI upset to severe Acute Radiation Syndrome (ARS) and death. The primary acute treatment for radiation exposure is removal from exposure and decontamination. Triage with tools such as the START algorithm (REMM: Radiation Emergency Medical Management) (Figure 3) facilitate patient care in mass casualty scenarios, otherwise the majority of patient care for radiation exposure occurs in the hospital setting.

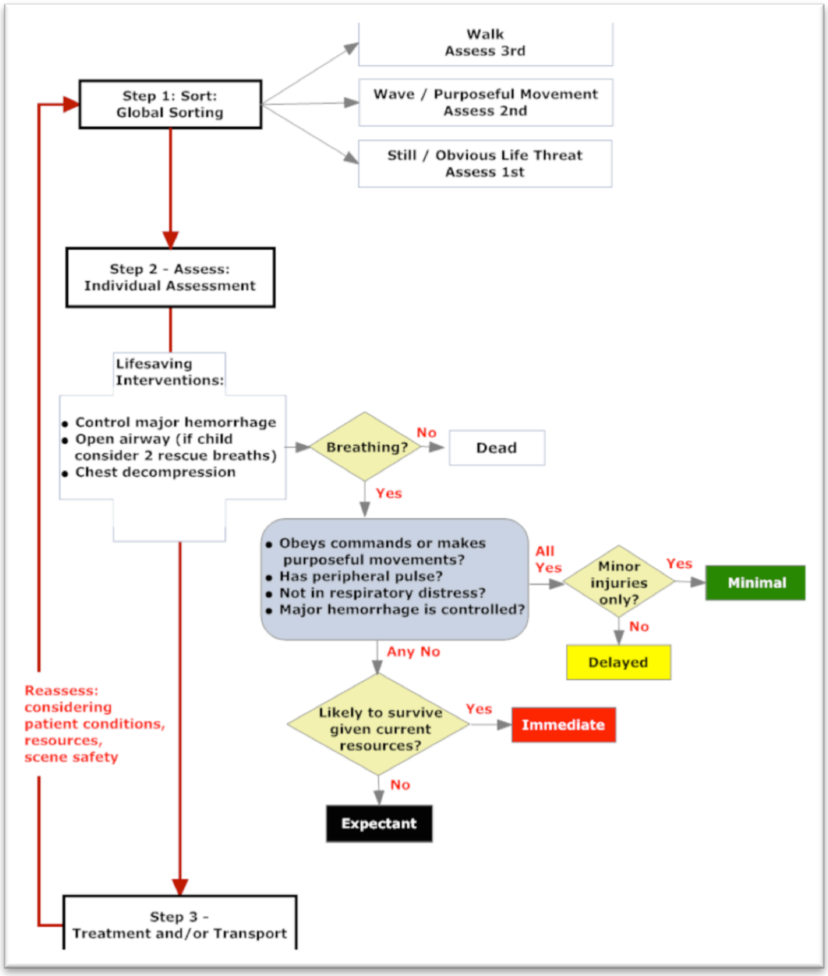

Figure 3. The START triage guidelines for initial medical response to radiological casualties.

4. Use of a CNS in CBRN Environment

There are four key concepts in CBRN counter-proliferation operations, which make a CNS advantageous. These four concepts are: Limit personal exposure, SME input can be critical (technically, legally and medically), multitasking is high in CP missions (takes away from situational awareness), and many of the medical indications of exposures have early biometric signals.

By using a CNS to monitor and assist in medical care, the team performing the mission may be able to decrease the amount of operators exposed. Especially if combined with remote monitors and video capability, the team can afford to lessen the physical presence of otherwise necessary individuals.

SME input on CP missions can be vital to force protection as well as evidence capture and technical disarming. By having the capability to transmit vital signs, images and sensor inputs, the CP team can better determine the correct actions to take. When faced with an odd or unknown exposure, the team can reach out to SME's in the United States to assist in diagnosis and treatment. Physicians and CBRN experts can for SME support teams to monitor and standby to support the team with key information.

Multitasking on a CP mission is highly stressful and can easily lead to an operator ignoring key biometric signs. By remotely monitoring the individual operator's vital signs, a distant team can identify operators who have been exposed to and agent much more quickly. Even if a portion of the team had a deadly exposure, the remote monitoring team could warn the rest of the team prior to their exposure. For example, if a five-man team was securing a certain room in a lab and became exposed, the remote monitoring team could warn the follow-on team working the adjacent hallway before they became exposed. As biometric monitoring becomes more advanced, determining stress related changes vs. toxin exposure might become easier.

Due to the generally rapid onset of physiological effects, the chemical environment is perhaps the most interesting area for a CNS to function. The system can serve to alert operators of exposure prior to feeling the effects of the chemical they have been exposed to. In general, soldiers are taught symptoms of chemical exposure and appropriate actions to take after feeling these effects. These symptoms are late systemic effects of the exposure. If the individual operators could be warned prior to feeling these effects, they could potentially significantly decrease their exposure time and decrease their time to treatment. The CNS is capable of tying in to existing chemical sensors when transmitted wirelessly, thus further increasing the sensitivity and specificity of diagnosis.

Due to the longer incubation period, the biological CP missions may not experience as great a benefit in a CNS for medical purposes. One area, which would see benefit, is in using a CNS in a known exposure area. By evaluating actively sick patients with the capabilities of the CNS, remote providers can tap into an SME team standing by to assist in diagnosis and treatment. The CNS system could even be used by the infected individuals to assist themselves in caring for each other, thus decreasing exposure of healthy medical providers.

Given that radiation symptoms are triaged based off of directly observable data such as respiratory rate, perfusion, and breathing status, remote biometric devices could assist in the early detection of ARS. When tied into radiological detectors, the CNS can greatly increase accuracy and medical treatment algorithms by providing exact vital signs and precise exposures. Armed with this information the CP team can potentially extend their operable time or more efficiently rotate those directly exposed.

B. CIVILIAN EMS

The Casualty Network System has obvious direct benefits in the civilian EMS realm. Imagine sitting at a restaurant when you start having severe chest pain. The ambulance is called; a paramedic arrives and places an IBD onto your chest. The ECG and key vital signs are delivered directly to the nearest hospital, whose staff immediately starts tracking your medical condition while giving direct feedback to the attending paramedic. When you arrive at the hospital the staff already knows exactly what your vital signs have looked like over the past 20 minutes, any allergies or medications you are on and what medications you have received. In fact, the staff has already been a key member of the EMS team aiding your treatment since well before you arrived to the emergency department.

Several EMS departments are already starting to employ telemedicine capabilities in day-to-day operations. This employment increases diagnostic capacity and accuracy of field paramedics as well as enhances patient handoff at the Emergency Department. The CNS is much easier to implement and use in the civilian setting given the wide availability of established cellular networks, greater equipment carrying capability, and decreased demands for operational security. Such a system could be integrated into the already widely distributed network of AED's throughout the country, thus giving a more direct and quicker link to the Emergency Department staff. Airlines currently are employing medical devices capable of transmitting 12 lead ECGs, vital signs and video feeds to on call medical centers. In fact, given the high cost to divert an airline, the airline industry has led the way in acquiring telemedicine capabilities.

C. HUMANITARIAN ASSISTANCE AND DISASTER RELIEF (HADR)

HADR operations are very demanding in terms of intelligence and logistics. One of the most difficult aspects to HADR operations is matching the casualties with the appropriate providers and resources. The CNS has the potential to serve as an impromptu network in HADR settings to match providers, resources and casualties. Given that the system may function on any smartphone, relief providers may install the application to their phone and couple with IBDs. The CNS app will allow providers to input data from the surroundings they encounter. The data may include: number of casualties, services and equipment available, resources needed, security status, disease outbreaks, and number and level of providers in the area. This data will be uploaded through existing cellular networks, satellite link, UHF radio or ad hoc networks to a central website. The provider data will be displayed geographically, indicating location of providers and the data, which was input by that provider. This data will be displayed on a map and will be color-coded by a needs to resources ratio. By forming an ad hoc social network, the response network will have instant access to real time intelligence. This real time intelligence will serve to identify areas of concentration for HADR efforts, supply drops and casualty evacuation areas. Rather than waiting on a central agency to take charge and direct, responders will be able to refine intelligence and act according to gaps identified in the system.

As data is entered into the system, a real-time picture of the disaster area will develop, allowing both individual users and authorities to maximize efficiency in resources available. For example, a nearby hub of providers can identify a hub of casualties. Once the two hubs recognize the disparity in resources to needs, the providers can relocate to assist those in need. This will have a net effect of leveling the resources to needs, keeping a fluid state of response. As the response authority is established, it can use the network to decide on where to set up its base of operations, evacuation routes and priorities. Further, it may use the CNS to direct providers to areas identified as most in need. As the response continues, the CNS can be used to monitor relief efforts, supply demands and infectious disease emergence. This continual monitoring will further maximize the efficiency of the relief efforts.

To verify quality of data, personnel who enter data to the system will be identified as a registered or non-registered user. Registered users will be those who register in the system and have credentials verified (from EMT to MD, as well as HADR coordinators). This will allow data collection from anyone, yet those accessing the information will be able to verify the data source.

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V. TOWARD AN IDEAL HANDOFF

Prior to implementing any technology solution in to battlefield operations, proper experimentation must be accomplished. This experimentation will allow better realization of capabilities, discover how the system integrates into current systems of communication, and how best to implement the final product. The objective of the experiment process will be to use current COTS products to pass casualty information over currently used tactical networks. As experimentation is performed, data collected can be analyzed to more effectively guide acquisition and product modification.

Experimentation will attempt to simulate a “real-world” environment reflecting current military operations. The experiment will simulate a casualty in the field being transferred to a TACEVAC platform, and then on to a CSH. Key players include: the casualty (human simulated), the medic, the TACEVAC (UH-60 with crew and flight medic), the CSH (real world local hospital with trauma team), the Observer Controller group (OC) located in the Tactical Operations Center (TOC), and the ground force which forms the tactical network.

A. CONSTRAINTS

Identification of constraints sets the left and right limits of the experiment and gives guidance to providers of technical solutions. The first constraint is amount of broadband. The technical solutions provided must not take up excessive amount of broadband from the tactical network. In general, when casualties are received, the network will be filled with other users as they coordinate and communicate the current fight. Technical solutions should not take more than 15% of the available broadband within the tactical network. The second constraint is the number of radios forming the tactical network. In general the system should be able to function with no more than 8 ground radios (RF or SER). The third constraint is environment; the system must work in both urban and remote environments. Finally, the system must be able to work in remote environments with no available existing communication networks such as cellular.

B. VARIABLES

Variables allow further discovery of system behaviors under different circumstances. By adding variables to the experimentation phase, more meaningful data can be collected for further research and implementation. Initially there will be five variables introduced for experimentation. The first variable is the number of casualties. Each system should be able to accommodate one to five casualties for initial testing. Initial experiments will be conducted with one patient, and then patients will be added with further experiments. The second variable will be the rate of data updates. In an ideal world the casualty information will be updated by the second, however this increases the demand on the system. Testing will be done to evaluate the system (both technical and human) and it's response to varying update rates (i.e., sending updates every 5 seconds vs. every 60 seconds). The third variable is the information passed. There currently are several designs of IBD's and each has varying amounts of information transmitted from the casualty. Some send only a SpO2, some send SmO2, BP, RR, Pulse and SpO2. By testing different vital signs inputs, we can better provide a picture to the end user of how their requirements function within the system. The fourth variable is the type of tactical network formed. Currently some military units are starting to use software-enabled radios (SER's), while many still use Radio Frequency only radios (RF's). The experimentation will include testing on RF and SER tactical networks. The final variable in the experimentation is the use of Wi-Fi technology to pass information. Ideally the casualty information will be passed wirelessly from patient to medic and into the tactical network. However, there is no current standard for permissible Wi-Fi on the battlefield. This requires experimentation using currently allowable technology (no Wi-Fi) as well as experimentation with likely future capability of secure means of wireless transmission for the future.

C. EXPERIMENT STRUCTURE

The objective of the experiment structure is to provide the framework for an experimentation campaign aimed at using technology to solve the combat medical handoff problem. If properly structured the experimentation structure will result in a collaborative effort between commercial civilian vendors, researchers and end operator users. By providing the framework and structure for the experimentation collaborators will be able to come together to receive requirements, perform discovery testing, analyze data and work together to more efficiently provide an optimal working solution. This solution can then be fielded more rapidly and completely than individuals performing separate experiments in a vacuum.

The experimentation team is made up of five elements as depicted in Figure 2. The central element is the casualty, which will tie all of the elements together. The casualty element is made up of several human simulated casualties. These casualties will provide the data to enter into the system. By using humans, the actual observed vital signs can be recorded and then cross-compared to observed end data received through the system. The second element is the ground medic element. The ground medic can be one to two experienced medics who will both receive data from the IBD's used as well as input the data of simulated injuries and treatments performed. The third element is the TACEVAC medic. The TACEVAC medic should be composed of a single experienced flight medic who both receives casualty information as well as inputs updated patient status and treatments performed. The final medical care element is the trauma team. A single experienced trauma provider, receiving data from a remotely located hospital (simulating an FST), may represent the trauma team. Finally, the observer controller element (OC) is the end element. The OC team will function primarily out of the Tactical Operations Center (TOC) and serve to capture data throughout the experiment. Commercial vendors will insert into each applicable element based on their technical capabilities.

Element	Location	Job	Data In/Out
Casualty/ies	Field	Simulate Injured Patient	Data In
Medic	Field	Casualty Care	Data In & Out
TACEVAC	Field	Casualty Care, Transfer of Patient	Data In & Out
Trauma Team	Hospital (FST)	Casualty Care Data Reception	Data Out
OC Team	TOC	Record Data, OC	Data Out

Table 1. Table depicting the experiment elements and their roles.

Upon completion of the experiment, data will be analyzed to provide feedback to participants and end users on performance of the system. For optimal analysis of the data, a timeline as depicted in Figure 4 will be constructed. The timeline shows four elements (casualty, medic, TACEVAC, and trauma team), depicting the data each receives over time. This will allow after action comparison of what data was received at which time through screenshot capture. This timeline of data received will allow the experimenters to compare accuracy of data as well as timeliness of data. For example, if we see that the trauma team did not receive data until the patient arrives, then the experiment will have failed to complete data transfer in a timely manner. This timeline will also allow for a more complete picture for end users to evaluate how well a system functions based on the composition of which products are used.

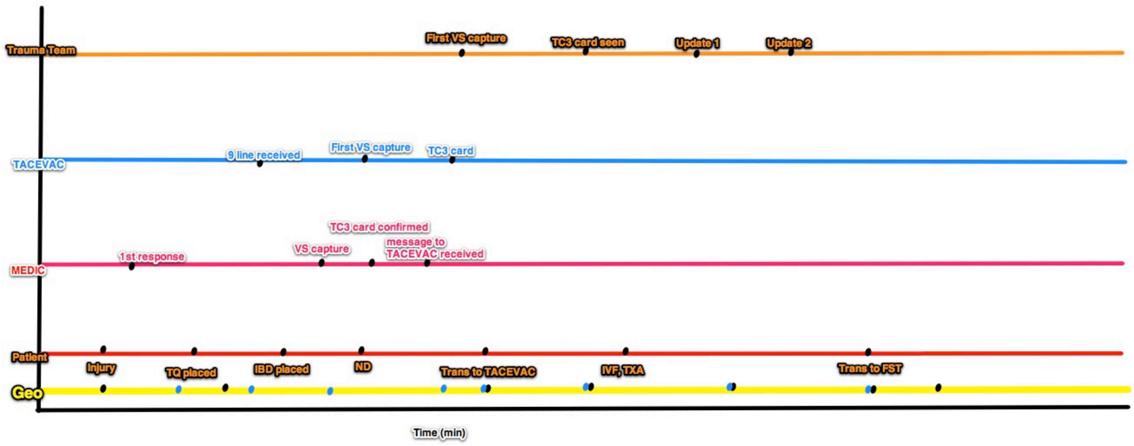

Figure 4. Timeline showing data captured for each element.

While a single experiment in time serves to test a capability, the ultimate objective of this process is to produce and field a quality product in a timely manner. In order to accomplish this the single experiment must be transitioned into an experimentation campaign. In order to facilitate an ongoing experimentation campaign several actions must take place. The first action is providing a testbed for ongoing experiments. Currently, the Naval Postgraduate School provides an ongoing Tactical Network Testbed (TNT) at Camp Roberts, which fully accomplishes this requirement. The Camp Roberts TNT provides the infrastructure, backside support, facilities, required environments and logistical support required for this ongoing experimentation campaign. Next, quality data analysis must be provided to all participants. This data is fed to end operators as well as participants, further fueling research and design for future experiments. A well set up experiment design with proper data analysis will draw commercial vendors to continued participation in the campaign, by providing them with critical feedback based on realistic testing. Once the data is received, analyzed and distributed, further design requirements will be generated. These design requirements will lead to modifications of the experimental variables and constraints. As depicted in Figure 4, this process sets up an ongoing experimental campaign process. This process leads to system refinement and fielding of products, which meet the requirements of the end operators.

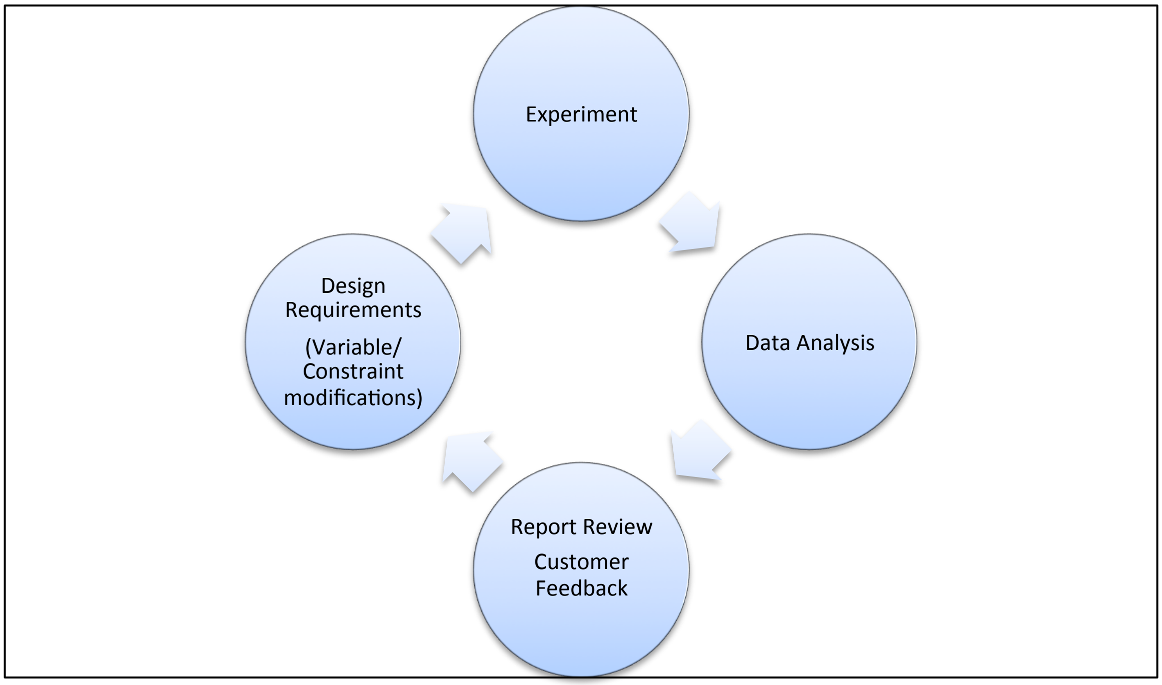

Figure 5. Experiment campaign cycle.

The casualty handoff process in combat remains a prevalent problem in today's theatres of operation. Current technology exists to adequately solve this problem, ultimately reducing morbidity and mortality on the battlefield. The primary reason that this technology is not currently employed is that minimal direction is being given to the industry for requirements of a Casualty Network System. With dissemination of basic requirements and a well-designed experimentation campaign, researchers, operators and civilian developers can more efficiently and quickly field an optimal working solution.

LIST OF REFERENCES

Barabasi, Albert-Laszlo (2002). *Linked, the new science of networks.* Cambridge, MA: Perseus Publishing.

Battaglia, Frederic (2011). *Ultra-wideBand (UWB) Army products overview.* Irvine, CA: Starix.

Carter, Alix; Davis, M. K., & Evans, M. L. (2009). Information loss in emergency medical services handover of trauma patients. *Prehospital Emergency Care, 13*, 280–285.

Chlamtac, Imrich, Conti, Marco, & Liu, Jennifer (2003). Mobile Ad Hoc Networking: Imperatives and Challenges. *Ad Hoc Networks*, 13–64.

Joint Commission. (2006). *National patient safety goals: 2006 critical access hospital and hospital national patient safety goals.* The Joint Commission.

Mistry, Kshitij; Landgren Christopher (2005). Communication error during post-operative patient hand off in the pediatric intensive care unit. *Critical Care Medicine, 33*, A12.

National Research Council (2000). *To err is human: Building a safer health system.* Washington, D.C.: The National Academies Press.

Radiation Emergency Medical Management. (n.d.). *START adult triage algorithm.* Retrieved September 25, 2012, from REMM, Radiation Emergency Medical Management, http://www.remm.nlm.gov/startadult.htm#illustration

United States Army Medical Research Institute for Infectious Disease. (2011). *Medical management of chemical casualties handbook* (Vol. 7). Fort Detrick, MD: U.S. Government Printing Office.

Watts, Duncan, & Strogatz, Steven (1998). Collective dynamics of ‘small-world’ networks.” *Nature, 393*, 440–42.

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